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THERMOCHEMICAL CONVERSION OF AGRICULTURAL RESIDUES TO ENERGY

RP/RAF/85/627

THE REPUBLIC OF THE SUDAN

Technical Report*

January/February 1986

Prepared for the Government of the Republic of the Sudan
by the United Nations Industrial Development Organization
acting as the executing agency for United Nations Development Programme

Based on the work of M. Valk
Expert in the thermochemical conversion of
agricultural residue to useful energy

United Nations Industrial Development Organization
Vienna

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ACRONYMS AND ABBREVIATIONS

BTG : Biomass Technology Group, Twente University of Technology, the Netherlands
ERC : Energy Research Council
FA : Forest Administration
HHV : Higher Heating Value
LHV : Lower Heating Value
mcwb : Moisture Content on Wet Basis
MEM : Ministry of Energy and Mining
NEC : National Electricity Corporation
NEA : National Energy Administration
RERI : Renewable Energy Research Institute
SEP : Special Energy Programme of the Federal Republic of Germany
SREP : Sudan Renewable Energy Project
UNDP : United Nations Development Programme
UNSO : United Nations Sudano-Sahelian Office

UNITS

kJ : kilojoule
km : kilometer
LS : Sudanese Pound
m : meter
m^3 : cubic meter
MW : megawatt
t : metric ton (1000 kg)
TOE : Tons of Oil Equivalent (41.8 10^6 kJ)
US$: United States Dollar
yr : year

EXCHANGE RATE ULTIMO JANUARY 1986

1 Sudan Pound (LS) = 0.30 United States dollars (US$)

CONTENTS

I INTRODUCTION

1.1 The purpose of this report is to identify specific projects in energy recovery from agricultural residues in the Republic of the Sudan. The time set for this activity was one month, of which one week for home base work and three weeks in January 1986 for field research, traveling, briefing and debriefing in Vienna. An important part of the field work was the collection of relevant reports and the interviewing of persons involved in the subject. It appears that there are several reports concerning the energy situation in Sudan and the utilisation of agricultural residues as an energy resource, but that they are not very well known to most of the people involved.

II SUMMARY AND CONCLUSIONS

2.1 The present report approaches matters of thermochemical biomass energy conversion in the Republic of the Sudan from two different sides, first the development of new resources and secondly the improvement of conversion efficiencies.

2.2 In order to assess the importance of various possibilities, Chapter III reviews the energy consumption in the whole Sudan. It is concluded that in the field of efficiency improvement only measures in the domestic sector (including charcoal production for households) may contribute substantially to a solution for the problem of deforestation. Pilot projects in biomass fueled industries may strengthen this industrial sector. For this reason industrial implementation possibilities will be investigated as well. Finally, it is concluded that biomass based alternative fuels, whether allocated to industry or households, can be of considerable importance with respect to a reduction of wood fuel consumption.

2.3 In Chapter IV the potential contribution of various options is discussed. <u>New resources:</u> It appears that groundnut shells are only of minor significance. Bagasse is more important. The most realistic estimate of its contribution to fuel wood saving is 0.6-1.3 % (baled or pressed) or 1.6-1.8 % (carbonised) of the annual wood fuel consumption. The reason for this difference is that in the latter option carbonised bagasse is mixed with molasses. With a potential of saving 3-[illegible] % of the annual wood fuel consumption, cotton stalks are of considerable importance. <u>Improvement of carbonisation efficiency:</u> It is concluded that a programme to improve carbonisation techniques in Sudan cannot contribute to saving of wood fuel. <u>Domestic fuel wood consumption:</u> In view of the necessary reduction of fuel wood consumption, the development of new resources is not enough. However, improvement of cooking efficiencies can contribute considerably to this goal. <u>Industrial energy consumption:</u> It is shown that the brick industry and the edible oil industry are the most promissing sectors for more efficient energy use. Before the economic feasibility of improvements in the brick industry can be discussed, research on the Sudanese brick making technology must be carried out.

2.4 Chapter V discusses the state of the art in the development of various new resources (cotton stalks, bagasse and groundnut shells) as well as of the design and dissemination of improved cookstoves. It is concluded that the economic feasibility of directly briquetting and of combined carbonisation/briquetting <u>cotton stalks</u> has not yet been sufficiently studied. Both technologies need further research. For the expected <u>bagasse</u> surplus, baling is the first necessary step in case the bagasse is to be used as a substitute for fuel wood or charcoal. Suitable technologies for the processing of bagasse exist. The most attractive options for the energetic use of <u>groundnut shells</u> are direct combustion (in boiler furnaces and in cookstoves) or combustion after briquetting (in bakeries and in brick kilns). The feasibility of the briquetting technology is not considered in the present report, but is treated extensively in Refs. 10 and 23. Finally, it is concluded that projects aiming at introduction of more efficient charcoal stoves are in need of a strong impulse. especially with respect to the design of an efficient and cheap model.

2.5 In Chapter VI the economic feasibility of a bagasse baling plant at Guneid Sugar Factory and of cogenerating heat and power in oil mills is discussed. It is concluded that bagasse baling and subsequent sale to biomass fueled industries is a profitable option. Bagasse bales can be delivered in Omdurman Industrial Area at competative prices. Compared to incineration of the bagasse surplus, this option shows a pay-back time of 0.74 yr. The option of installment of condensing turbo-gensets at the sugar factories and sale of surplus electricity to the grid, as proposed by a World Bank/UNDP mission (See Ref. 25), is still under consideration. It is recommended to consider this option also in relation to the alternative of bagasse baling and sale to wood fueled industries. The alternative of surplus electricity production may be more profitable but is certainly far more problematic from an organizing point of view. Due to want of time during the stay in Sudan only general remarks concerning cogeneration in oil mills are made.

Recommendations

2.6 The Mission recommends to:

- Start a pilot project at Guneid Sugar Factory for bagasse baling and sale of bagasse bales to biomass fueled industries.
- Strengthen the current cookstove projects with mechanical engineering capacity (combustion and industrial design experts).
- Continue research on the conditioning of cotton stalks. with special attention to the design of a cotton coal/molasses briquette and a suitable production process.
- Start research of Sudanese brick making technology in order to assess the importance of options for improvement of this sector.
- Undertake a feasibility study of cogeneration of heat and power in vegetable oil industries.

III REVIEW OF ENERGY CONSUMPTION

3.1 To get more insight into the importance of various energy resources and ways of energy conservation, a review of energy consumption in the Sudan is given. In Table 3.1 the most recent estimates (1980) of the Ministry of Energy and Mining are presented. 85 % of the total energy consumption is in the form of wood, charcoal and other biomass, 14 % is in the form of petroleum products and 1 % in the form of hydropower.

Table 3.1 Total energy consumption in 1980 in the Republic of the Sudan (10^3 TOE)*

Sector	Hydro-power	Benzene/ Avgas	LPG	Kerosene Jet Fuel	Gasoil	Diesel	Furnace Oil	Wood	Charcoal	Other Biomass	Vegetable Oil	TOTAL**	% OF TOTAL**
Industry	-	-	0.8	0.9	43.5	6.4	100.1	95.9	-	94.5	-	342.1	4.9
Transport	-	207.0	-	46.6	296.2	-	21.0	-	-	-	-	570.6	8.2
Agriculture	-	-	-	-	94.5	Small	-	-	-	-	-	94.5	1.4
Commercial Government Services	-	-	Small	-	9.2	-	-	83.9	87.1	-	-	180.2	2.6
Construction Oil Exploration	-		-	Small	34.2	-	-	-	-	-	-	34.2	0.5
Households	-	-	4.7	17.5	32.1	-	-	3,366.9	1,763.3	402.6	8.5	5,596.2	80.4
NEC Electricity Generation	63.5	-	-	-	21.2	14.4	42.5	-	-	-	-	141.6	2.0
TOTAL**	63.5	207.0	5.5	65.0	531.0	20.8	163.6	3,546.7	1,850.4	497.1	8.5	6,959.0	100.0
% OF TOTAL**	0.9	3.0	0.1	0.9	7.6	0.3	2.4	51.0	26.6	7.1	0.1	100.0	

*: Source: Ref.18: Petroleum imports from Kenya are excluded.
**: Totals may not add due to roundings.

Fuel wood consumption

3.2 There is no recent reliable estimate of the growing stock volume of the national forest resource in the Sudan. Based on random checks a World Bank/UNDP mission estimates that the growing stock volume in 1982 was of the order of 1.994 million m^3 (Ref. 2). The annual allowable cut was estimated at 44.3 million m^3 growing stock. On the other hand total wood consumption in 1980 was 76 million m^3 growing stock which was mainly used as fuel wood: 71 million m^3 (Ref. 18). This estimate of the Ministry of Energy and Mining is based on the assumption that the yield of charcoal making is only 17 % at average. However, recent measurements of traditional charcoal kilns show a much better performance, to a yield of about 30 % (Ref. 11). Real wood consumption may therefore be substantially lower, but is at least 50 million m^3/yr growing stock volume. The figures in Table 3.2 show that the total wood consumption is much higher than the allowable cut. On basis of the estimates by the Ministry of Energy and Mining the total wood consumption must be reduced by 42 % to equal the estimated allowable cut.

3.3 Table 3.1 shows that 80 % of the Sudanese energy consumption is domestic. 92 % of the energy used in households is in the form of fuel wood or charcoal. One third of the energy used in households is consumed as charcoal. In Table 3.2 estimates are given of the growing wood stock volume which is equivalent to this consumption pattern.

Table 3.2 Growing stock volume equivalent to annual wood fuel consumption in sectors

Sector	Annual energy consumption (10^3 TOE/yr)	Growing stock volume equivalent (10^6 m^3/yr)	
		16.6 % yield*	30 % yield**
Domestic fuel wood consumption	3,366.9	23.5	23.5
Domestic charcoal consumption	1,763.3	44.1	24.2
Industrial fuel wood consumption***	95.9	0.7	0.7
Other sectors			
- fuel wood	83.9	0.6	0.6
- charcoal	87.1	2.2	1.2
TOTAL	5397.1	71.1	50.2

*: Estimates based on figures of the Ministry of Energy and Mining, which assumes 16.6 % charcoal conversion yield (Ref. 18).
**: Based on 30 % charcoal conversion yield as measured by Osman Satti and Marlowe Dorré (Ref. 11).
***: Charcoal production industry excluded.

3.4 In the data provided by the Ministry of Energy and Mining, charcoal production is not considered an industry.

From Table 3.2, however, it can be concluded that charcoal making consumes a considerable amount of energy. Depending on the avarage carbonisation yield (30-16.6 %) it represents 11.9-31.8 10^6 m^3 growing stock per year. A conversion yield of 30 % must be considered as the maximum attainable. With a view to wood saving, charcoal production may not be ignored.

Biomass fueled industries

3.5 Compared to the domestic sector industry consumes only a minor quantity of fuel wood. Efficiency improvements in this sector cannot contribute much to wood saving. On the other hand a more efficient use of biomass fuels may help to strengthen individual industries.

3.6 Industries which depend for a substantial part of their energy consumption on biomass energy are (See Table 3.3):

- the sugar industry,
- the vegetable oil industry,
- the brick industry,
- the bakeries.

From these industries only the vegetable oil industry, brick industry and bakeries use fuel wood. Chapter IV reports about alternative possibilities in those industries.

Table 3.3 Industrial energy consumption in 1980* (10^7 TOE)

Sector	Electricity	Petroleum products	Biomass	Total (=100 %)
Bakeries	- (0 %)**	4.8 (11 %)	39.9 (89 %)	44.7
Brick kilns	- (0 %)	- (0 %)	37.5 (100 %)	37.5
Cement	4.8 (18 %)	21.8 (82 %)	- (0 %)	26.6
Oil and soap industry	3.6 (8 %)	23.6 (49 %)	20.6 (43 %)	47.8
Sugar industry	6.1 (4 %)	44.8 (33 %)	85.9 (63 %)	136.8
Textile industry	9.7 (31 %)	21.8 (69 %)	- (0 %)	31.5
Others	-	26.6 (96 %)	1.2 (4 %)	27.8

*: Source: Ref. 18
**: In brackets: Share of total in %

Conclusion

3.7 The Mission concludes that only those efficiency improvement measures which are taken in the domestic sector (including charcoal production for households) may contribute substantially to a solution to the deforestation problem. Pilot projects in biomass fueled industries may strengthen the industrial sector. Possibilities in this sector will be investigated as well. Development of alternative fuels, whether allocated to industry or households, can be of considerable importance with respect to a reduction of wood fuel consumption.

IV POTENTIAL OF VARIOUS POSSIBLE IMPROVEMENTS IN THE ENERGY SECTOR

IV.1 Improvements with respect to a reduction of fuel wood consumption

4.1 The consumption of fuel wood can be reduced in three ways, viz. i) by developing alternative fuels, ii) by improving carbonisation efficiencies in traditional charcoal making and iii) by introducing a more efficient cookstove which is economically attractive for potential users.

New resources

4.2 In this chapter the availability of the following potential alternative fuels is considered:
- cotton stalks,
- bagasse and molasses,
- groundnut shells.

4.3 Several studies have been carried out to assess the annual amount of cotton stalks which is burnt on the fields for legal reasons (See Refs. 5, 6, 9, 23, 24). These studies take more or less account of grazing and of use by the tenants. A reliable estimate is an annual yield of 1.0 million ton cotton stalks. With a lower heating value of 16.000 kJ/kg, this represents 0.3 10^6 TOE/yr and is equivalent to 2.1 10^6 m^3 growing stock (wood) per annum. This potential may replace 3-4 % of annual wood fuel consumption (See Table 7.2).

4.4 Cane sugar is produced by 4 government-owned factories (at Asselaya, Guneid, New Halfa and Sennar) and by one private company (at Kenana). During the Mission's visit, the cane sugar rehabilitation programme (as referred to in Ref. 25) was near completion. If it is successful an enormous bagasse surplus will develop in the near future. Cane sugar factories use their bagasse for the purpose of cogenerating process steam and electric power. The latter is used for mill power and for irrigation. Exceptions are Kenana, which exports electricity to NEC, and New Halfa which does not need electricity for irrigation. Before the rehabilitation there was no bagasse surplus, except in New Halfa. For an estimate of the potential bagasse surplus, Kenana will be left out of account.

4.5 To assess the potential bagasse surplus, use is made of a report, prepared by Merz and McLellan (Ref. 12) by order of the Ministry of Finance and Economic Planning, in which the feasibility of electricity export by the cane sugar factories to NEC is studied. The study is based on data provided by Tate and Lyle, in a report which is the basis of the rehabilitation programme, and on data obtained during field visits. Estimates of the potential bagasse surplus are based on realistic assumptions concerning the yearly sugar production, the number of season days, the load factor of the various sugar factories and mean values for the fibre content of the cane. With an assumed mean fibre content of 15-19 %, the potential bagasse surplus in the government-owned factories is 200.4-434.3 10^3 t/yr (mcwb: 0.50).

4.6 Wet bagasse (mcwb: 0.50, LHV: 7,400 kJ/kg) can be directly combusted to raise process steam and electric power. Combusted directlty the above quoted bagasse surplus represents a thermal energy amount of 35-77 10^3 TOE/yr. This amount cannot be used entirely by the sugar factories. Surplus power must be sold to the NEC grid. In this manner the bagasse does not replace fuel wood, but fuel oil and possibly, if the generators are not run wisely, hydropower from the NEC. The latter, of course, would be a dissipation of resources. The NEA staff told the Mission that the option to raise surplus electric power for export to the grid was not yet approved of. Since the rehabilitation programme is near completion, a consideration of other options is very significant.

4.7 Other possibilities for processing the bagasse surplus are: i) baling (mcwb: 0.20), ii) briquetting or pelleting (mcwb: 0.08) and iii) carbonisation. In all three ways the bagasse surplus may replace industrial and domestic fuel wood. The technical and economical feasibility of these options is discussed in Chapters V and VI.

4.8 In case of baling the bagasse, the bagasse bales dry to mcwb: 0.20. The potential bagasse surplus reduces with a factor 0.62 to 124-269 10^3 t/yr, while the LHV increases to 13.510 kJ/kg (See Annex 1). Therefore the potential amount of thermal energy represented by baled bagasse is 41-86 10^3 TOE/yr, which is equivalent to 0.31-0.65 10^6 m^3 growing stock (wood) per annum. This may replace 0.4-1.3 % of the annual wood consumption.

4.9 In case of briquetting or pelleting the bagasse, the mcwb and consequently the bagasse surplus reduce to 0.08 and 107.8-233.7 10^3 t/yr respectively while the LHV increases to 15.900 kJ/kg (See Annex 1). Bagasse briquettes or pellets therefore represent a potential of 42-89 10^3 TOE/yr, which is about the same as for bagasse bales.

4.10 In 1939 a bagasse carbonisation process was developed in Indonesia (Ref. 22). In this process bagasse charcoal briquettes are made by mixing bagasse charcoal with molasses. The yield in this process is 100 kg briquettes from 270 kg bagasse (mcwb: 0.20) and 100 kg molasses. The amount of briquettes that potentially can be produced in this way is 50-100 10^3 t/yr. Assuming the same LHV as for wood charcoal this represents 36-72 10^3 TOE/yr. Since this fuel may replace charcoal this amount is equivalent to 0.5-1.8 10^6 m^3 growing stock (wood), which is 1.0-2.5 % of the annual wood fuel consumption.

4.11 Usually molasses are not considered as replacement for wood fuel but, instead, as a resource for ethanol production, and thus as having a potential for replacement of petroleum products. However, because of its importance in the production of the above mentioned fuel briquettes (See also Chapter V), the availibility of molasses demands further consideration. At present molasses are hardly used in the Sudan. A negligible part is processed in the animal fodder industry. The rest is either dumped or exported from Port Sudan against transportation cost. Assuming that the rehabilitation programme as proposed by Tate and Lyle is successful, the amount of molasses is 266,600 t/yr (Ref. 25). If molasses are processed into fuel briquettes, its resulting moisture content can be estimated at 0.10 (mcwb). The corresponding LHV is estimated at 8,700 kJ/kg (See Annex 1) and thus it represents 55 10^3 TOE/yr, which is equivalent to 0.4 10^6 m^3 growing stock (wood), or 0.5-0.8 % of the annual wood fuel consumption. However, since the ratio of molasses to charcoal is a limiting factor, it is not likely that this entire potential can be used in a briquetting industry.

4.12 Schmitt and Siemers (Ref. 23) present an extensive review of total production and availability of groundnut shells. Their sources are the Yearbooks of Agricultural Statistics (1974-1984) and the Current Agricultural Statistics (1984) from the Ministry of Agriculture, some reports of the National Energy Administration (Refs. 13-17), as well as field visits. One of the conclusions is that groundnut production is very unstable (due to irregular rainfall and degradation of cultivated land and has decreased considerably from an average of 613,000 t/yr during 197[illegible]-81 to about 426,000 t/yr at present. Since this decline is mainly due to the drought, the shelling percentage, which was about 25 % in good seasons, increased to about 30 %. Therefore, on basis of these figures, projected annual groundnut shell production for the next years may be estimated to be 128,000 t/yr. Another estimate (Ref. 6) gives a shell production of 300,000 t/yr, but does not allow for the production decrease over the last 10 years. In Ref. 28 a maximum secure shell supply of 176,000 t/yr is estimated.

4.13 This amount, however, is not entirely available for development of a new energy source. The reason is that the shells are already partly used as fuel, i.e., as boiler fuel in vegetable oil mills, as additive in brick manufacturing and also for domestic cooking. Though groundnut shells have no nutritional value, groundnut shells are also partly used as additive to animal fodder. However, while assessing the potential for the development of a new energy source, that part must be considered as economically competing with a fuel on basis of groundnut shells and cannot be excluded beforehand from such a development. There are no reliable estimates of the share of shells which is already used as a fuel. However, from figures presented in Ref. 23 concerning the shell surplus in the rain fed areas, where shells are scarcely used as an additive to fodder, one may conclude that it is in the order of 45 % (± 10 %). So, the shell surplus which is potentially available for the development of a new fuel can be estimated at about 70,000 t/yr (on basis of the production figures of Schmitt and Siemers). With a LHV of 18,000 kJ/kg this represents 30,100 TOE/yr or 0.21 10^6 m^3 growing stock (wood) per annum. It may replace 0.3-0.4 % of the annual wood fuel consumption.

Improvement of traditional carbonisation efficiency

4.14 In Chapter III it is shown that the charcoal industry is an important consumer of energy. Recent and cautious research (Ref. 11) shows that the traditional Sudanese kilns have a very high conversion efficiency of about 0.30 (weight of charcoal vs. weight of wood fuel; weights on dry basis). Therefore it is not likely that significant efficiency improvements in charcoal manufacturing can be realised.

Improvement of domestic cooking efficiency

4.15 In the domestic sector. fuel wood is particularly used in rural areas, while charcoal is especially used in urban areas. At present no wood stoves are used in Sudan, instead wood fuel is used in simple open fires. From Table 3.2 it can be concluded that 95 % of the fuel wood is consumed in the domestic sector. Depending on the carbonisation efficiency, 51-65 % of this quantity is used in the form of charcoal. The National Energy Plan 1985-2000 (Ref. 20) shows that the charcoal demand will grow faster than the wood demand since urban growth will be faster than rural growth (The urban population prefers charcoal rather than wood). So, though at the moment both fuels are equally important with respect to fuel conservation, it may be expected that the relative importance of charcoal will increase. Therefore. in stove projects priority is given to charcoal stoves (See also Ref. 18).

4.16 The efficiency of open fires has not been investigated in the Sudan but. contrary to the common opinion that a normal open fire has less than 6% efficiency (e.g. Ref. 25). research in other countries shows an average efficiency of 14% (Ref. 3). The traditional Sudanese charcoal stove is a simple square metal stove with a metal grid and open draft. This stove has an efficiency of 18 % (Ref. 7). With improved cookstoves these efficiencies can nearly be doubled (Ref.1), thus reducing the annual fuel wood consumption by 48 %. However, this is a matter of the long term.

Conclusion

4.17 From Table 4.1 conclusions concerning the importance of various new resources may be drawn. Groundnut shells are only of minor significance. Bagasse is more important. The most realistic estimate of its contribution to fuel wood saving is 0.4-1.3 % (baled or pressed) or 1.0-2.0 % (carbonised). The reason for this difference is that carbonised bagasse is mixed with molasses. Potentially saving 3-4 % of the annual wood fuel consumption cotton stalks are of considerable importance. Note that transportation cost is not considered here. It will depend on the production scale and may be of considerable influence.

Table 4.1 Potential savings obtained by developping new resources

Resource	Potential saving		
	energy (10^3 TOE/yr)	growing stock equivalent (10^3 m^3)	share of annual wood fuel consumption (%)
Cotton stalks	300	2100	3* -4**
Bagasse			
- bales	41-86	310-650	0.4* -0.8* 0.6**-1.3**
- briquettes/pellets	42-89	318-673	0.4* -0.8** 0.6**-1.3**
- charcoal (with molasses)	36-72	900* -1800* 500**-1000**	1.3* -2.5* 1.0**-2.0**
Molasses	depending on mixing ratio in briquettes		
Groundnut shells	30	210	0.3* -0.4**

*: Estimates based on figures of the Ministry of Energy and Mining, which assumes 16.6 % charcoal conversion yield (Ref. 18)

**: Based on 30 % charcoal conversion yield as measured by Osman Satti and Marlowe Dorré (Ref. 11)

4.18 From reliable investigations by Osman Satti and Marlowe Dorré (Ref. 11) it may be concluded that a programme to improve carbonisation techniques in Sudan cannot contribute much to saving of wood fuel.

4.19 In view of the necessary reduction of fuel wood consumption, the development of new resources is certainly not enough. Improvement of cooking efficiencies can contribute considerably. Priority should be given to charcoal cookstoves.

IV.2 Energy saving in biomass fueled industry

4.20 Tables 3.2 and 3.3 show that bakeries, brick kilns and the oil and soap industry are the only important biomass fueling industries, using about 1 % of the total Sudanese wood fuel consumption. Possibilities for fuel saving in these industries and for potential utilisation of agricultural residues are investigated and comprehensively discussed in a recent report (Ref. 23), of which the importance is emphasised.

4.21 Concerning traditional bakeries Schmitt and Siemers suggest the following possible improvements:

- Reduction of the baking temperature and corresponding prolongation of the baking period,
- Improvement of combustion efficiencies,
- Complete separation of combustion and baking chamber,
- Testing of alternative fuels from new resources.

Since compared to modern efficient ovens the traditional Sudanese bakeries show a rather good efficiency, improvements may be expected to be of minor importance. Also the technical feasibility of these improvements is not yet known and should be tested before implementation. Besides, as many bakeries turn to electricity and/or oil, it may be doubted wether there is an economic incentive to implement the above mentioned improvements.

4.22 The second important wood fuel consuming industry is brick manufacturing. The energy efficiency of the production process, if related to the amount of good quality bricks, is low. The reason is that a large share (up to about 30 %) of the bricks is wasted, due to over- or under-burning and/or to poor quality of the green bricks. This industry can therefore be improved substantially. Every quality improvement of green bricks production leads to an improvement of energy efficiency. An improvement of kiln construction and/or firing method in order to reduce the amount of under- and over-burnt bricks, however, might eventually lower the kiln energy efficiency. It is possible that in this respect the present kilns are optimum. Possibilities for improvements of kiln design and firing method can only be assessed by means of a research programme in which the bricks are made from a good mixture of clay, organic material and water, and are dried carefully and slowly. Such a study has not yet been undertaken.

4.23 Oil mills need process heat and power. Power is usually generated by diesel gensets or taken from the grid. The installed power ranges from 20-200 kW, depending on mill size. Process steam is raised in steam boilers fueled with wood or agricultural residues (e.g. groundnut shells) or with fuel oil. Saturated steam pressures range from 3-6 bar. Unfortunately there are no data available on processing capacities and on process heat and power consumption in this sector. General energy consumption figures for the oil and soap industry (Ref. 18) indicate that it is possible to bring heat and power generaton in tune in a cogenerating steam plant. Sudanese oil mills which cogenerate their energy need are not known to the Mission, nor are they mentioned in relevant literature (See Ref.23).

<u>Conclusion</u>

4.24 The brick industry and the edible oil industry are the most promissing sectors for energy use improvements. Before the economic feasibility of improvements in the brick industry can be discussed, research on the Sudanese brick making technology must be carried out. The economic feasibility of cogeneration in the edible oil industry must be further investigated (See Chapter VI).

V STATE OF THE ART AND FUTURE DEVELOPMENTS IN BIOMASS ENERGY IN SUDAN

5.1 In this chapter results of past research and present projects are reviewed. Also necessary and possible developments are indicated.

V.1 Direct use and conditioning of fuels from new resources

Cotton stalks

5.2 The use of cotton stalks has been the object of several technical and/or economical studies. The following options have been considered:

- direct combustion in power plants during the harvesting season (Ref. 24),
- briquetting (Refs. 6, 24),
- gasification (Ref. 6),
- carbonisation, whether or not combined with briquetting of the charcoal (Refs. 4, 5. 6, 8, 9, 26).

5.3 Ref. 24 presents a system for large-scale collection, transport and handling of cotton stalks from the Gezira scheme, chipped in the field and transported to a 10 MW power plant by train. Cost estimates for smaller power plants (0.5 and 3 MW) are also presented. One of the conclusions is that power generation from chipped cotton stalks is not economically feasible.

5.4 The economic feasibility of a large scale briquetting factory is discussed in Ref. 24. The report describes a briquetting factory with a capacity of 120,000 t/yr, corresponding to an area of 50,000 feddans. The estimated cost of cotton stalks briquettes, not including storage of the briquettes, is about 30% too high to be competitive with gasoil fuel for steam raising in power plants. Calculations in Ref. 6 of the costs of cotton stalks briquetting show that it can be competitive with the price of carbonised cotton stalks.

5.5 The proper direct-briquetting technology has not yet been established. Ref. 6 recommends a series of tests with a piston press to investigate the various scientific aspects concerning the phyto-sanitarian problems. The National Council of Research in Khartoum has acquired a hydraulic piston press. Establishment of a pilot plant for direct briquetting of cotton stalks at one of the headquarters of the Gezira Board or Rahad scheme is recommended by Hood (Ref. 9). Such a pilot plant offers the possibility to study the practical problems in the whole system as well as the phyto-sanitarian control problems.

5.6 Ref. 6 reports that only a fluidised bed gasifier is suitable for gasification of cotton stalks. This process is technically complex. It is economically feasible in a power range of 250 kW_e and above. Such a unit needs 8 t/day of shredded stalks and is, due to the high cost of transport and storage, not a suitable solution.

5.7 A reliable technology to meet the phyto-sanitarian requirements is carbonisation. Estimates concerning economically feasible scales are made in Refs. 4, 5, 6, 9, 26. Because of high transportation cost, centralised carbonisation results in high cotton coal production cost. Large-scale carbonisation is unable to produce a charcoal which is competitive with charcoal from wood. Refs. 4, 5 and 26 conclude that small-scale on-the-field carbonisation of cotton stalks is economically feasible.

5.8 Ref. 5 discusses some designs of simple kilns suitable for the carbonisation of cotton stalks. Hood and Zorge (Ref. 26) present the design of a new kiln and its performance in the first trial runs. From the Mission's visits to the technicians involved in these projects it appears that these technologies are promissing with respect to carbonisation efficiency (30 % has been reached) and quality.

5.9 Though the carbonisation quality is good, the quality of the produced charcoal causes some problems for transport and combustion in cookstoves. The charcoal is very crisp, light and probably more reactive than charcoal from wood, due too a larger micro-porosity. Transport is difficult, leading to an unacceptably large share of fines. On account of the low density it is impossible to put enough fuel in a conventional cookstove. Combustion conditions, and consequently the role of reactivity, in charcoal stoves are not yet understood well. A fact is that the charcoal from cotton stalks burns too fast. This means that the cotton charcoal must be further conditioned, viz. briquetted, to meet the requirements of transport and use in cookstoves.

5.10 When the Mission visited the projects involved in the development of cotton charcoal briquetting processes, it appeared that the influence of reactivity was not yet recognised and distinguished from the influence of density. All present research is aimed at producing charcoal briquettes of sufficient strength and density. Ref. 5 describes a simple charcoal briquetting press (that can be produced in a village workshop) which is alleged to be the most appropriate device for on-the-field briquetting of carbonised cotton stalks. In a research project from ERC and SREP a piston briquetting press is being developed (Ref. 8). However, the Mission holds the opinion that pressing alone cannot affect the microporosity and thus reduce the reactivity.

5.11 Based on laboratorium tests performed by BTG (Twente University of Technology) the Mission expects that the reactivity of the cotton stalks charcoal can be reduced and the density increased sufficiently by mixing the char with cane sugar molasses. In a briquette which can be formed from the ground char the molasses serve as a binder as well. The technology is not yet fully developed. Proper molasses/charcoal ratios must be assessed and a production process must be developed. In Chapter III the availibility of molasses is discussed.

Bagasse

5.12 Baling bagasse is a usual technology, practised in many cane sugar producing countries. Factories have a choice between incinerating without making use of its energetic value and baling their surplus in order to store it and use it later. In Sudan only the sugar factories at Sennar and Asselaya have bagasse balers, though at present this equipment is not used. To assess the fuel quality the volume ratio and the weight ratio of bagasse bales versus wood of the same heat content are calculated. For two bale types, densities of respectively 355 and 555 kg/m^3 are reported (Ref. 22, recalculated to mcwb 0.20). The LHV of the bales is 13,510 kJ/kg. That of Acasia fuel wood is 18,000 kJ/kg and its density is 800 kg/m^3 (Ref. 11). From these values it appears that, with the same heat content, 1 m^3 of fuel wood corresponds to 1.9-3.0 m^3 of bagasse bales and that 1 kg of wood corresponds to 1.33 kg of bagasse bales. On dry basis the volatile matter content of wood and bagasse bales are about the same. Because these values do not differ too much, industrial furnaces can be loaded sufficiently when fueling bagasse bales. For this reason the Mission expects that bagasse bales of proper size are an excellent replacement of wood fuel in industrial furnaces, without causing a need for retrofitting. Typical baling sizes are: 450x560x810 mm^3 and 300x300x500 mm^3. These sizes are too big for direct fueling of industrial furnaces with the bales. If the sugar factories decide to make bagasse available for appliance in various industries, they must install balers which produce smaller bales of approximately 500x150x150 mm^3. A visit to an oil mill in Omdurman (AL FADL OIL INDUSTRIES) confirmed the willingness of the owner to replace fuel wood by bagasse bales. He had tried to fuel his process steam boiler with unprocessed bagasse, which lead to handling problems only.

5.13 The Forestry Administration and the FAO department in Khartoum, in cooperation with a French company (CEAR), developed two types of a bagasse molasses briquette, one from dried and one from carbonised bagasse (Ref. 27). The main equipment used are a manual press and, for the carbonised briquettes, a 7 m^3 kiln. The briquettes made from uncarbonised bagasse are a suitable replacement of wood fuel, whereas the briquettes made from carbonised bagasse may well replace charcoal. Results concerning acceptability and performance in domestic use are satisfactory. The briquettes have not yet been tested in industry. The briquette development was concentrated at New Halfa sugar factory, which, before the rehabilitation, was the only factory with a bagasse surplus. The bagasse surplus at New Halfa was partly fermented and dried. A large share of the bagasse used in the manufacture of the uncarbonised-bagasse briquettes was from this dry stock, since this material gave the strongest briquettes. In case in the near future bagasse/molasses briquettes are to be produced at other sugar factories with differing conditions, the process must be adapted accordingly. Especially the possibility to use baled bagasse (mcwb 0.20) must be tested, since this is the most likely condition in which the bagasse can be made available.

5.14 Direct briquetting or peletting of pre-dried bagasse is not a commonly applied technology. Even though storage cost of bagasse bales are high, baling is the cheaper alternative.

Groundnutshells

5.15 In the rain fed areas a recent development is the use of the groundnut shells in oil mill boilers for generation of process steam. The shift from wood fuel to shells is enforced by rising fuel wood prices. The handling and combustion performance of the shells is quite different from fuel wood but causes little problems.

5.16 At some places groundnut shells are combusted directly in a cookstove of a special design. A sketch is presented in Figure 1 (See Annex 2). The combustion takes place in the inner vertical channel. This channel is formed around a stick which during loading is placed in the center of the stove and after loading is removed. The body is shaped in the form of a bucket with an opening at the bottom.

5.17 Groundnut shells are a good material for briquetting. As the fuel characteristics of groundnut shell briquettes are comparable with fuel wood, the briquettes can serve as a fuel wood substitute (See Ref. 10). In 1985 a groundnut shells briquetting programme was started by the UNSO, the Danish government and the NEA. Apparently, there is a division of opinion concerning the economical feasibility of such a project since Ref. 23 states that groundnut shell briquettes are too expensive in comparison to fuel wood.

5.18 To produce a substitute for charcoal from wood, groundnut shells can be carbonised in a Herreshoff kiln (See Ref. 6), the smallest of which has a capacity of 50.000 t/yr. This amount is of the order of the total Sudanese groundnut shell surplus (See Chapter IV). Groundnut shells carbonisation is therefore not a likely development.

5.19 Though Ref. 6 investigates the economical feasibility of a fluidised bed groundnut shells gasification plant for process heat and electric power supply to a groundnut oil mill, fluidised gasification of groundnut shells is not at all a proven technology. Only shelling plants and/or oil mills should be considered for a groundnut shells gasifier. However, gasification is not the most appropriate technology for these industries (See Chapter VI).

V.2 Charcoal stove projects

5.20 In 1983 the Sudan Renewable Energy Project (SREP) started a stove project to commercially develop and disseminate a stove designed by the University of Khartoum and Afhad College for Women, the Canun-el-Duga. Two versions of this new design, an open-draft model and a controlled-draft model are schematically shown in Figure 2 (See Annex 2). The advantages of this new design are (Ref. 7):

- Its efficiency is about 25 %, which is approximately 39 % better than the traditional metal stove.
- In contrast with traditional stoves, the stove accepts charcoal fines.
- It is easy to use.
- The cooking time is decreased.

The current dissemination rate is about 850 stoves per month, which, in view of the necessary reduction of fuel wood consumption, is not much (See Chapter IV).

5.21 The reason of this slow implementation is probably the high production cost of the Canun-el-Duga. The price of a Canun-el-Duga is about LS 15, whereas a traditional stove costs only about LS 3. This problem is clearly recognised in Ref. 8. Still, the report expects that further progress in dissemination of these improved charcoal stoves can be made by better understanding of the market and improvements in production technique. Apparently, the design is considered adequate from a technological point of view. For the dissemination of the new stoves the RERI formed a Technology Development and Dissemination Unit.

5.22 The RERI, an affiliate of the Energy Research Council, at present develops a second design, the Jiko, modelled after a Kenian stove. This stove consists of a clay grate and body, fitted in a metal housing (See Figure 3, Annex 2). The production cost of this model are probably low. Efficiency data are not yet available.

V.3 CONCLUSIONS

New resources

5.23 As to the use of cotton stalks the two options of direct briquetting and of combined carbonisation briquetting should be further evaluated. Both technologies need further research. The expected bagasse surplus must be baled as a first step to use bagasse as a substitute for fuel wood or charcoal. The economical viability of baling and further processing needs further study. Suitable technologies for the further processing of bagasse exist. The most attractive options for the energetic use of groundnut shells are direct combustion (in boiler furnaces or in cookstoves) and combustion after briquetting (in bakeries or brick kilns).

Charcoal stove projects

5.24 The projects trying to introduce more efficient charcoal stoves are in need of a strong impulse, especially with respect to the design of an efficient and cheap model.

VI THE ECONOMICAL FEASIBILITY OF SOME NEW PROJECTS

6.1 In this chapter the feasibility of a bagasse baling plant is discussed. A pre-feasibility study of cotton coal/molasses briquette production is currently being prepared (Ref. 2). Finally, some short remarks are made concerning cogeneration in oil mills.

VI.1 Bagasse conditioning at Guneid sugar factory

6.2 It is expected that in the near future the bagasse surplus will become a severe problem for the sugar factories (See Chapter IV). The factories have a choice to either install incinerators, to bale and sell the bagasse or to produce surplus electricity and sell this to NEC. The sale of electricity requires a large investment and is not likely to be realised at short notice (See Chapter IV). Merz and McLellan (Ref. 23) did not consider the sale of bagasse bales to industry. For this reason the incinerating and baling options will be reconsidered here.

6.3 This study is set up as a case study for Guneid Sugar Factory. The production figures are taken from Ref. 23 with the fibre content as the main parameter. At Guneid, the mean fibre content over the season is estimated to be 16 %, resulting in a projected bagasse surplus of 63.130 t/yr. The average exess bagasse is estimated at 311 t/day. The number of working-hours is set at 8 hr/day. The influence of assuming 22 hr/day is shown in Annex 4.

Bagasse incineration cost

6.4 Cost incinerating bagasse decreases with lower incineration capacities. Storage of a certain amount of bagasse, and incineration during an accordingly longer period in smaller incinerators may therefore be profitable. It should be noted, however, that storage needs imporant investments (Belt conveyors, bulldozers, trailers, storage area) and also calls for operating costs. Adequate sizing of incinerator capacity is therefore a matter of optimization. The two extreme cases of i) smallest possible incineration capacity combined with large storage facilities and ii) incineration capacity according to the average surplus bagasse production, will be considered here. The storage volume is limited because of the danger of fire hazards. The experience in New Halfa is that bagasse can be stored without any processing or covering for a few months. The season being about 203 days/yr, it is assumed in this study that the entire bagasse surplus can be burnt during the whole year. If the number of annual working days is set at 300 days/yr the needed storage and incinerator capacitiesare 20.500 t (at end of crop) and 210 t/day respectively. Bagasse (as produced) density is 160 kg/m³. Therefore, storage of this amount of bagasse needs an area of 25,600 m² (Bagasse piled-up to 5 m height). Bagasse handling can be carried out by one bulldozer and a tractor with three 6 x 2.45 x 2 m^3 trailers. The area must be prepared with a concrete floor and walls. From the overview of investment costs (Table 6.1) it can be concluded that both options will be almost equal in their economic performance. The most simple solution, viz. incineration without storage, will be taken as a reference for evaluation of installing and operating a bagasse baling plant. Cost per ton incinerated bagasse amounts to 6.45 US$/t, see Table 6.2.

Table 6.1 Investment and annualized costs of a bagasse incineration plant at Guneid Sugar Factory, System A: With storage capacity, incineration capacity 26 t/hr; System B: Without storage capacity, incineration capacity 40 t/hr.

Cost item	System A			System B		
	Lifetime (yr)	Investment cost (US$)	Annualized* cost (US$/yr)	Lifetime (yr)	Investment cost (US$)	Annualized* cost (US$/yr)
Incinerator**	25	1,925,000	212,075	25	2,540,000	279,827
30,000 m^2 Storage area (a 10 US$/$m^2$)	30	300,000	31.824	-	-	-
1 Bulldozer	10	50.000	8.137	-	-	-
1 Tractor with 3 trailers	10	21.090	3.426	-	-	-
TOTAL		2.296,090	255.462		2,540.000	279.827

*: Under the assumption of a fixed discount rate of 10 %/yr.

**: Including feeding system and ash removal system.

Bagasse baling cost

6.5 The bagasse baling capacity is determined under the assumption that baling on an as produced basis is the cheapest solution, namely, 40 t/hr. Storage must be assured for two month. During this period the bales dry. Subsequently they are transported and sold. Two month storage corresponds to a storage capacity of 18.037 t. The bales are piled-up to a height of 9 m in stacks of 20 x 37 m on an area of 13.730 m^2 (Including room for claiming and reclaiming). Necessary equipment and its cost is mentioned in Table 6.3. In Table 6.4 cost per t baled bagasse is calculated, viz. 3.32 US$/t (mcwb 0.50). After drying the amount of bagasse reduces with a factor 0.62. Thus, production cost per t dry baled bagasse is 5.35 US$/t (mcwb 0.20).

Table 6.2 Annual costs of a bagasse incinerating plant (Capacity: 40 t bagasse per hr) at Guneid Sugar Factory.

Cost item	Annual cost (US$/yr)
Annualized capital cost	279,827
Annual operating cost*	
- manpower:	
3 man year (unskilled)**	548
- maintenace and repair	127.000
(5 % of investment per yr)	
TOTAL	407,375
Cost per t bagasse (US$/t)	6.45

*: Feeding system power consumption excluded (Own generation).
**: Unskilled-labour cost: 0.9 US$/day, 203 day/yr.

Table 6.3 Investment and annualized costs of a bagasse baling plant at Guneid Sugar Factory. Capacity: 40 t/hr.

Item	Lifetime (yr)	Investment cost (US$)	Annualized* cost (US$/yr)
Baler	10	240,000	23,598
Building	30	220,000	23,337
13,730 m^2 Storage area (a 10 US$/$m^2$)	30	137,300	14,565
1 Bulldozer	10	50,000	8.137
1 Tractor with 3 trailers	10	21,050	3,426
TOTAL		668,350	73,063

*: Under the assumption of a fixed discount rate of 10 %/yr.

Market consideration

6.6 The wood fuel consumption in Khartoum Province in 1984 was 181,610 t/yr (3.27 10^{12} kJ/yr), see Ref. 21. The bagasse surplus at Guneid Sugar Factory is expected to amount to 0.62 x 63.130 t (mcwb 0.50)/yr = 39,141 t dry (mcwb 0.20) bagasse bales per year. With a LHV of 13,500 kJ/kg, this corresponds to 5.28 10^{11} kJ/yr, which is 16 % of the fuel wood energy consumption in the Khartoum Province industries. For convenience the economic performance of a bagasse baling plant will be related to the deliverance of bagasse bales at Omdurman industrial area.

Table 6.4 Annual costs of a bagasse baling plant (Capacity: 40 t bagasse per hr) at Guneid Sugar Factory.

Cost item	Annual cost (US$/yr)
Annualized capital cost	73,063
Annual operating cost*	
- baling wire	94,695
- labour:**	
skilled (4 man yr)	1,462
unskilled (2 man yr)	365
- maintenace and repair (5 % of investment per yr)	33,418
- diesel fuel***	3,756
TOTAL	206,759
Cost per t bagasse baled (US$/t, mcwb 0.50)	3,28
Cost per t bagasse baled (US$/t, mcwb 0.20)	5.28

*: Electric power consumption excluded (own generation).
**: Skilled-labour cost: 1.8 US$/day. 203 day/yr.
Unskilled-labour cost: 0.9 US$/day. 203 day/yr.
***: Diesel fuel cost set at 0.25 US$/l.

Delivered cost of bagasse bales in Omdurman

6.7 The distance from Guneid Sugar Factory to Omdurman Industrial Area is 138 km. The condition of the roads between the factory and Omdurman is excellent. Cargo transport costs by lorry depend on a large number of factors, among them variable costs like repair and maintenance. tires, fuel and lubricants, which are usually calculated on a per kilometer basis, as well as fixed costs as capital and labour which are normally calculated on a per time unit basis. For this pre-feasibility study the transport price is set at 0.12 US$/t km. assuming that a 40 t lorry can be loaded to full capacity. Transportation cost of dry bagasse bales to Omdurman amount to 15.36 US$/t. Total delivered cost of dry bagasse bales then amount to 20.64 US$/t. With reference to the energy content (LHV = 13,510 kJ/kg) the delivered cost of bagasse bales in Omdurman is 1.53 10^{-6} US$/kJ.

Prices

6.8 This figure can be compared with the price of energy from fuel wood. The avarage fuel wood price in Omdurman is 36 US$/t. or, with a LHV of 18,000 kJ/kg, 2.00 10^{-6} US$/kJ. which is 31 % higher than the delivered cost calculated for bagasse bales. Bagasse bales are therefore expected to compete well with fuel wood.

6.9 A break-even price for baling and selling the bagasse surplus, with reference to the option of incinerating the bagasse surplus, is determined as follows. The cost of incinerating the bagasse surplus is 407,375 US$/yr, whereas the cost of baling and selling amounts to 20.64 US$/t x 39,141 t/yr = 807,870 US$/yr. The incremental annual cost are 400.495 US$/yr. While processing 39,141 t dry bagasse bales per year, the option of baling and selling the bagasse surplus is to break-even at a price of 10.23 US$/t (0.76 10^{-6} US$/kJ), which in view of the price of energy from wood is very promissing.

Financial appraisal

6.10 Assuming that Guneid Sugar Factory is able to sell the bales for 23.91 US$/t (1.77 10^{-6} US$/kJ), its revenues amount to 935,861 US$/yr. Under the same assumption the payback period of the investment is 0.74 yr, which is very attractive.

6.11 Merz and McLellan (Ref. 23) calculate cost and benefits for the option to produce and sell surplus electricity to the grid. For Guneid Sugar Factory they propose to install a 7.5 MW condensing turbine generator set, for operation in base load. Cost and benefits are estimated to be 7.560.000 and 15.040.000 LS/yr, or at the exchange rate used, 2.268.000 and 4.512.000 US$/yr respectively. Although the net estimated benefits, 2.244,000 US$/yr, are substantially higher than in the case of baling and selling the bagasse surplus, the mission is of the opinion that the baling option may not be discarded immediately. Electricity export to the grid requires the solving of severe organizing problems, like the co-operation with NEC and the negotiation of tariffs. The question whether NEC is able to accept surplus electricity from the sugar factories is not considered by Merz and McLellan. Contrary to electricity production, baling and selling of bagasse can be organized easily.

Conclusion

6.12 Baling is a profitable alternative to incineration of the bagasse surplus. It should be considered also as an alternative to installment of condensing turbo-gensets and sale of surplus electricity to the grid.

VI.2 Cogeneration of heat and power in oil mills

6.13 Cogeneration of heat and power may be an interesting option for vegetable oil mills, especially for those plants which geerate their own electricity from diesel fuel. Its economic feasibility should be investigated thoroughly. Unfortunately the Mission's stay in Sudan was too short so as to enable the Mission to select and visit oil mills not connected to the grid.

6.14 Cost of energy supply may be reduced further by replacing diesel oil or fuel wood by milling wastes. Many oil mills process various sorts of seeds, e.g. cotton seeds, sesame seeds and groundnuts. Only groundnut wastes are a potential alternative for fuel wood. Therefore, fueling with groundnut shells should be included in the consideration. Due to the varying production, groundnut shells are not always available. Consequently they cannot entirely replace fuel wood. Therefore a multi-fuel boiler (wood/groundnut shells) must be applied. This is only possible with direct combustion furnaces, not with gasifiers. Moreover, the gasification of groundnut shells is not yet technically feasible. For this reason the following alternatives should be evaluated:

A) Installment of a multi-fuel (wood/groundnut shells) process steam boiler/furnace and of a diesel power generator.
B) Installment of a multi-fuel (wood/groundnut shells) boiler/furnace, cogenerating motive power and process steam;
C) Installment of a wood gasifier, cogenerating motive power and process steam;

Special attention should be paid to the advantage provided by the possibility of fueling groundnut shells in Alternatives A and B. This advantage stands out most in Alternative B.

ANNEX 1 HEATING VALUES

The following lower heating values are made use of:

Acasia fuel wood:

LHV = 18,000 kJ/kg (wet basis).

Bagasse:

LHV = 17.765 - 5,020 suc - 20,270 mcwb kJ/kg,

with suc = sucrose mass fraction (All values on wet basis).

It is assumed that the sucrose mass fraction of bagasse is 0.025 and that the moisture content is 0.505.

Molasses:

There are no heating values mentioned in literature referred to in this report. Molasses are a mixture of water, sugars (sucrose, glucose, fructose), other carbohydrates, ash, nitrogenous compounds, non-nitrogenous acids, wax, sterols and phospholipids. Sugars are the must important compound. At average cane sugar molasses contain 51 % sugars, 20 % water and 12 % ashes (wet basis). Based on averaged values of the composition of cane sugar molasses, as presented in Ref. 11, the following estimate ± 10 % is made of the lower heating value:

LHV = 7,500 kJ/kg (wet basis, mcwb 0.20).
LHV = 8,700 kJ/kg (wet basis, mcwb 0.10).

For the purpose of the present study these values are give with sufficient accuracy.

Cotton stalks:

LHV = 16,000 kJ/kg (wet basis).

Groundnut shells:

LHV = 18,000 kJ/kg (wet basis).

ANNEX 2 SUDANESE IMPROVED COOKSTOVES

Figure 1: Groundnut shell cookstove.

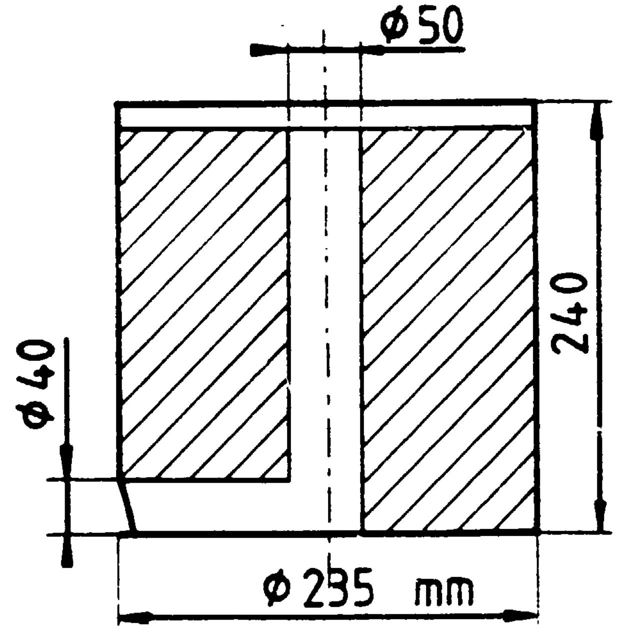
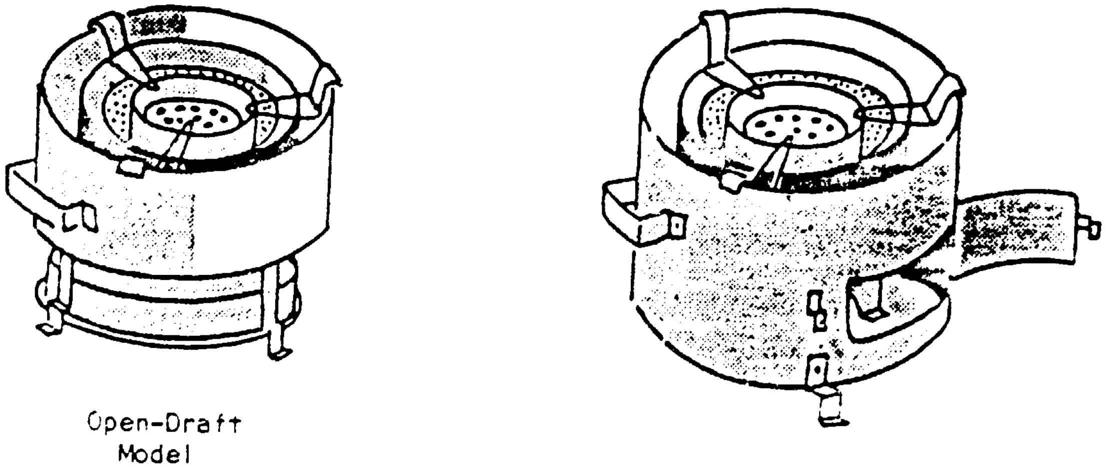


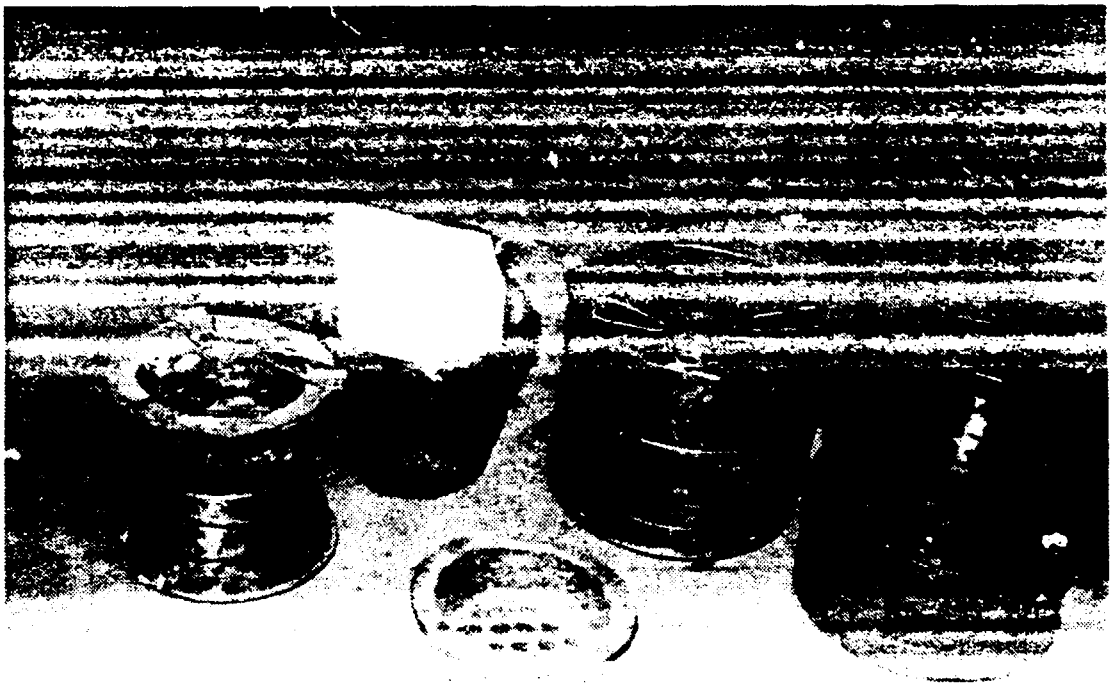
Figure 2: Canun-el-duga. Source: Ref. 7.



Open-Draft Model

Controlled-Draft Model

Figure 3: Three Sudanese improved stove types. From the left to the right: the Jiko, a sawdust stove and two Canun-el-duga.



ANNEX 3 BAGASSE BALING AT GUNEID SUGAR FACTORY, ASSUMING 22 WORKING-HOURS PER DAY

A3.1 Assuming 22 working-hours per day (instead of 8 working-hr/day. Chapter VI), the capacities of considered incinerating and baling plants change accordingly. Costs of incinerating plants are shown in Tables A3.1 and A3.2. Alternative B, without storage, is now clearly less expensive than alternative A, due to the omittance of storage capacity and equipment. Direct incineration is therefore taken as a reference to the baling option. Incineration cost amounts to 2.30 US$/t (mcwb: 0.50).

A3.2 Costs of bagasse baling, making use of a 14.1 t/hr baler, are reviewed in Tables A3.3-A3.4. In this case the cost of delivering bagasse bales at Omdurman industrial area amounts to 20.15 US$/t or 1.49 10^{-6} US$/kJ (mcwb: 0.20).

A3.3 The break-even price for baling and selling the bagasse surplus, with reference to incineration, is 16.44 US$/t or 1.22 10^{-6} US$/kJ (mcwb:0.20). In case of selling the surplus for 21.75 US$/t (1.61 10^{-6} US$/kJ), annual revenues amount to 851.360 US$/yr. The corresponding pay-back period is 0.60 yr.

Table A3.1 Investment and annualized costs of a bagasse incineration plant at Guneid Sugar Factory. System A: With storage capacity. incineration capacity 9.6 t/hr; System B: without storage capacity. incineration capacity 14.1 t/hr.

Cost item	System A			System B		
	Lifetime (yr)	Investment cost (US$)	Annualized* cost (US$/yr)	Lifetime (yr)	Investment cost (US$)	Annualized* cost (US$/yr)
Incinerator**	25	718.000	79.100	25	895.350	98.640
30.000 m^2 Storage area (a 10 US$/$m^2$)	30	300.000	31.824	-	-	-
1 Bulldozer	10	50,000	8,137	-	-	-
1 Tractor with 3 trailers	10	21.050	3,426	-	-	-
TOTAL		1,089,050	122,497		895,350	98.640

*: Under the assumption of a fixed discount rate of 10 %/yr.
**: Including feeding system and ash removal system.

Table A3.2 Annual costs of a bagasse incinerating plant (Capacity: 14.1 t bagasse per hr) at Guneid Sugar Factory.

Cost item	Annual cost (US$/yr)
Annualized capital cost	98,640
Annual operating cost*	
- manpower:	
9 man year (unskilled)**	1,644
- maintenace and repair (5 % of investment per yr)	44,770
TOTAL	145,054
Cost per t bagasse (US$/t)	2.30

*: Feeding system power consumption excluded (Own generation).

**: Unskilled-labour cost: 0.9 US$/day, 203 day/yr.

Table A3.3 Investment and annualized costs of a bagasse baling plant at Guneid Sugar Factory. Capacity: 14.1 t/hr.

Item	Lifetime (yr)	Investment cost (US$)	Annualized* cost (US$/yr)
Baler	10	84,600	8,318
Building	30	220,000	23,337
13,730 m^2 Storage area (a 10 US$/$m^2$)	30	137,300	14,565
1 Bulldozer	10	50,000	8,137
1 Tractor with 3 trailers	10	21,050	3,426
TOTAL		512,950	57,783

*: Under the assumption of a fixed discount rate of 10 %/yr.

Table A3.4 Annual costs of a bagasse baling plant (Capacity: 14.1 t bagasse per hr) at Guneid Sugar Factory.

Cost item	Annual cost (US$/yr)
Annualized capital cost	57,783
Annual operating cost*	
- baling wire	94,695
- labour:**	
skilled (12 man yr)	4.386
unskilled (6 man yr)	1.095
- maintenace and repair (5 % of investment per yr)	25,648
- diesel fuel***	3,756
TOTAL	187,363
Cost per t bagasse baled (US$/t, mcwb 0.50)	2.97
Cost per t bagasse baled (US$/t, mcwb 0.20)	4.79

*: Electric power consumption excluded (Own generation).

**: Skilled-labour cost: 1.8 US$/day. 203 day/yr.
Unskilled-labour cost: 0.9 US$/day, 203 day/yr.

***: Diesel fuel cost set at 0.25 US$/l.

ANNEX 4 LIST OF VISITS

ERC:

Mr. Shomo Sha'a Eldin Ali,
Assistent Coordinator, Special Energy Programme.

Mr. Gaafar El Faki Ali,
Assistent Coordinator SREP.

Mr. dr. El Tayeb Idris Eisa,
Coordinator SEP, Director ERC.

Mr. dr. Ahmed Hassan M. Hood,
Researcher Renewable Energy Research Institute.

Mr. dr. El Sheik E. M. Magzoub,
Project Leader Fuel Wood Combustion, Sudan Renewable Energy Project.

Mr. D.B. Peterson,
Georgia Institute of Technology, Chief of Party Sudan Renewable Energy Project.

Mr. dr. M.O. Sid-Ahmed,
Director Renewable Energy Research Institute.

Mr. dipl.-ing. Firouz Wakilzadeh.
Deutsches Gesellschaft fuer Technische Zusammenarbeit (GTZ GMBH). Solar Advisor Special Energy Programme.

Forests Administration:

Mr. J.B. Ball,
Project Manager, Fuelwood Development for Energy in Sudan (GCP/SUD/033/NET).

Mr. A. Paddon.
Biomass Energy Section Tropical Development Research Institute. Culham. Oxon, United Kingdom, Fuelwood Development for Energy in Sudan (GCP/SUD/033/NET).

NEA (Ministry of Energy and Mining):

Mr. M. Breuning,
Coordinator (UNSO/SUD/83/X04).

Mr. Jamal El Gazouli.
Director General NEA.

Mr. Mahmoud R. El Hakeim.
Conventional Energy Dept. NEA.

Mr. Mir Heydari.
NEA Senior Advisor Energy Planning and Management Project. Energy Development International.

Mr. D.W. Pluth,
Chief of Party Energy Planning and Management Project NEA,
Energy/Development International.

Industry:

Mr. Ahmed Mohamed Al-Fadl,
Owner and General Manager of Al-Fadl Oil Industries. P.O.Box 781 Omdurman.

Guneid Sugar Factory.

UNIDO (Khartoum):

Mr. F.M. Iqbal,
Director UNIDO Dept. Khartoum.

Mr. P. Versteeg,

Others:

Mr. M. Yoffé,
Senior Adviser Product Design and Marketing UNDP/ILO, c/o UNDP Khartoum.

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